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VERIFIED TRANSLATION OF PRIORITY DOCUMENT

The undersigned, of the below address, hereby certifies that he/she well knows both the English and Japanese languages, and that the attached is an accurate translation into the English language of the Certified Copy, filed for this application under 35 U.S.C. Section 119 and/or 365, of:

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[TITLE OF THE INVENTION] PIEZOELECTRIC ACTUATOR DRIVE CIRCUIT AND FUEL INJECTION SYSTEM

[CLAIMS]

[Claim 1] A piezoelectric actuator drive circuit having a charge/discharge circuit portion for charging and discharging a piezo-stack mounted on a piezoelectric actuator, a pair of positive and negative connection terminals connected to a current supply cable that extends to the piezo-stack, and an abnormality detection circuit portion for detecting an abnormal conduction of the current supply cable, wherein the abnormality detection circuit portion is characterized by;

a voltage detection means for detecting the voltage at the non-ground side connection terminal out of the connection terminals, and

a comparison means for comparing the detected voltage with the reference voltage that is set previously and for supplying a comparison signal.

[Claim 2] The piezoelectric actuator drive circuit according to claim 1, wherein the abnormality detection circuit portion is provided with a counting means for counting the number of times when the detected voltage exceeds the reference voltage between the charge command and the discharge command of the piezo-stack.

[Claim 3] The piezoelectric actuator according to claim 2, wherein a binary counter that is capable of two-bit counting is employed as the counting means comprising a two-step

D flip-flop circuit for resetting corresponding to the charge command.

[Claim 4] The piezoelectric actuator drive circuit according to claim 3, wherein;

the comparative means has the structure for generating a first comparative signal that rises when the detected voltage exceeds the reference voltage and a second comparative signal having the phase inverse to the first comparison signal that rises up when the detected voltage falls down below the reference voltage,

the abnormality detection circuit portion is provided with an S-R flip-flop circuit having a set terminal which receives the first comparison signal as the input and having a reset terminal which receives the second comparison signal as the input, and

an input value fixing means for fixing the input value of the set terminal or the reset terminal forcedly,

and the output signal of the S-R flip-flop circuit is supplied to the binary counter as the input signal.

[Claim 5] The piezoelectric actuator drive circuit according to claim 4, wherein a set input value fixing means that fixes the input value of the set terminal of the S-R flip-flop circuit to "L" when the output of the binary counter changes to "H" is provided as the input value fixing means.

[Claim 6] The piezoelectric actuator drive circuit according to claim 4 or claim 5, wherein a reset input value fixing means that fixes the input value of the reset terminal of the S-R

flip-flop circuit to "L" when the discharge command is supplied as the input is provided as the input value fixing means.

[Claim 7] A fuel injection system characterized by comprising an injector that switches between injecting and stopping of fuel by opening or shutting the injector by means of the piezoelectric actuator and a piezoelectric actuator drive circuit for driving the piezoelectric actuator according to any one of claim 1 to claim 6.

[DETAILED DESCRIPTION OF THE INVENTION]

[Technical Field of the Invention]

The present invention relates to a piezoelectric actuator drive circuit and a fuel injection system.

[Prior Art]

A piezoelectric actuator functions based on the piezoelectric effect of a piezoelectric material such as PZT. A piezo-stack, which is a capacitive element, expands or contracts by being charged or discharged, thereby exerting force on a piston, etc. to render a linear motion. An example of applications of the piezoelectric actuator that functions as the valve of a fuel injector of a fuel injection system for internal combustion engines are known. In the case of such a piezoelectric actuator, the driving force to the valve body and the valve lift for controlling the valve is set depending on the charge value of the piezo-stack.

The piezoelectric actuator drive circuit comprises a charge/discharge circuit for supplying a current to the piezo-stack and a controller for controlling the charge/discharge

current and charge value to form a unit. The piezoelectric actuator drive circuit is provided with a pair of positive and negative connection terminals, and the connection terminals are connected to the piezo-stack mounted on the piezoelectric actuator with a charge/discharge cable.

The piezo-stack expands when charged or contracts when discharged, and maintains the state unless the piezo-stack is charged or discharged next. For example, in the case of the fuel injection system of the internal combustion engine, because the fuel injection amount is determined by the length of the injection period, for example, the piezo-stack is charged at the beginning of the injection period to open the injector, the piezo-stack maintains the charged state during the injection period. Thereafter, the piezo-stack is discharged at the end of the injection period to close the injector.

However, if an abnormal conduction such as cable disconnection or contact failure to the connection terminal happens to occur, the piezo-stack cannot be charged or discharged and results in malfunction of the piezoelectric actuator. In the case of the fuel injection system, fuel is not injected when fuel is to be injected. On the other hand, for example, if the cable is disconnected after charging, the piezo-stack cannot be discharged to result in continuous fuel injection after the predetermined injection period further. In consideration of this problem, some of the fuel injection system is provided with a fail-safe function that functions mechanically to stop the fuel injection after elapse of a certain time so that serious failure

is not caused.

A detection technique described in JP-A-1-202177, the voltage between both ends of a current detection resistor provided in a current supply path connected to the piezo-stack is detected during charging operation. If the detected voltage value is lower than a predetermined threshold value, then it is determined that abnormal charging current does not flow due to conduction failure of the cable. By applying such a technique, charging to the piezo-stack or a set of the piezo-stacks having the common cable is prevented.

[Problem to be Solved by the Invention]

However, in the abnormality detection technique described in JP-A-1-202177, because the abnormality is detected based on the charge/discharge current, the abnormality detection timing is limited to the start or end of the injection period.

As a result, the complete disconnection can be detected definitely, but jittering in which disconnection and reconnection due to irregular contact to the connection terminal can be detected not always. Moreover, in the case of jittering, which is different from the complete disconnection in which the piezo-stack loses charge/discharge capability already, it could happen very often that the fuel injection cannot be stopped due to disabled discharge though the mechanical fail-safe function is operated.

The present invention has been accomplished in view of the above-mentioned problem, and it is an object of the present invention to provide a piezoelectric actuator drive circuit and

a fuel injection system that is capable of detecting the cable disconnection including jittering consistently.

[Means for Solving the Problem]

The invention described in claim 1 provides a piezoelectric actuator drive circuit having a charge/discharge circuit portion for charging and discharging a piezo-stack mounted on a piezoelectric actuator, a pair of positive and negative connection terminals connected to a current supply cable that extends to the piezo-stack, and an abnormality detection circuit portion for detecting the abnormal conduction of the current supply cable, wherein the abnormality detection circuit portion is characterized by being provided with;

a voltage detection means for detecting the voltage at the non-ground side connection terminal out of the connection terminals, and

a comparison means for comparing the detected voltage with the reference voltage that has been set previously and for supplying a comparison signal.

The voltage at the non-ground side connection terminal rises from 0V and exceeds the reference voltage when the piezo-stack starts to be charged in response to a charge command of the piezo-stack, and holds a voltage corresponding to the target charged capacity if the conduction of the current supply cable is not abnormal. On the other hand, the voltage at the non-ground side connection terminal falls down below the reference voltage and falls to 0V again when the piezo-stack starts to be discharged in response to a discharge command of the

piezo-stack. If the current supply cable happens to be disconnected while the piezo-stack is in the charge holding state, the voltage at the connection terminal, namely detected voltage, falls down below the reference voltage even though the piezo-stack holds the charged state, and the output of the comparison means is inverted resultantly. Thereby, the abnormal conduction of the current supply cable can be detected regardless of charging or discharging. Because the detected voltage changes up and down across the reference voltage when jittering occurs, the jittering can be detected easily.

The invention described in claim 2 provides the structure of the invention described in claim 1 wherein the abnormality detection circuit portion is provided with a counting means for counting the number of times when the detected voltage exceeds the reference voltage between the charge command and the discharge command of the piezo-stack.

The detected voltage rises up over the reference voltage during the charge, but falls down again when the abnormal conduction occurs on the current supply cable. In the case of jittering, the detected voltage rises up over the reference voltage again, and the detected voltage rises up over the reference voltage twice or more frequently. Therefore, if the current supply cable restored to the normal state before discharge, the abnormal conduction is detected based on the frequency.

The invention described in claim 3 provides the structure described in claim 2 wherein a binary counter that is capable of two-bit counting is employed as the counting means

comprising a two-step D flip-flop circuit for resetting corresponding to the charge command.

Because the output value of the binary counter, namely the output value of the upper bit D flip-flop circuit, changes to "H" when the detected voltage rises up over the reference voltage twice, the jittering can be detected thereby.

The invention described in claim 4 provides the structure described in claim 3 wherein;

the comparative means has the structure for generating a first comparative signal that rises when the detected voltage exceeds the reference voltage and a second comparative signal having the phase inverse to the first comparison signal that rises up when the detected voltage falls down below the reference voltage,

the abnormality detection circuit portion is provided with an S-R flip-flop circuit having a set terminal which receives the first comparison signal as the input and having a reset terminal which receives the second comparison signal as the input, and

an input value fixing means for fixing the input value of the set terminal or the reset terminal forcedly,

and the output signal of the S-R flip-flop circuit is supplied to the binary counter as the input signal.

The input value of the set terminal and the reset terminal of the S-R flip-flop circuit is fixed by means of the input value fixing means. Thereby, the output value of the binary counter or the output value of the S-R flip-flop circuit that is

obtained as the determination result of the abnormality can be held.

The invention described in claim 5 provides the structure described in claim 4 wherein a set input value fixing means that fixes the input value of the set terminal of the S-R flip-flop circuit to "L" when the output of the binary counter changes to "H" is provided as the input value fixing means.

The set terminal of the S-R flip-flop circuit will not change to "H" when the output value of the binary counter is "H" due to jittering, and the counting-up of the binary counter is inhibited. Thereby, the output value of the binary counter holds "H" that indicates jittering even through the detected voltage reciprocates frequently across the reference voltage due to jittering.

The invention described in claim 6 provides the structure described in claim 4 or claim 5 wherein a reset input value fixing means that fixes the input value of the reset terminal of the S-R flip-flop circuit to "L" when the discharge command is supplied as the input is provided as the input value fixing means.

The reset terminal of the S-R flip-flop circuit will not be changed to "H" even if the detected voltage falls down below the reference voltage due to discharge based on the discharge command, and the output value of the S-R flip-flop circuit holds "H" that indicates the normality of the current supply cable after the piezo-stack has been discharged during charge holding period of the piezo-stack under the condition that the current supply

cable is normal.

The invention described in claim 7 provides the structure that comprises an injector that switches between injecting and stopping of fuel by opening or shutting the injector by means of the piezoelectric actuator and a piezoelectric actuator drive circuit for driving the piezoelectric actuator described in any one of claim 1 to claim 6.

The abnormal conduction of the current supply cable can be detected also when the piezo-stack is charged or discharged. The abnormal conduction including jittering can be detected easily. As the result, the repetition of abnormal fuel injection involving frequent operation of the mechanical fail-safe mechanism can be avoided.

[DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS]

(First embodiment)

FIG. 1 and FIG. 2 show the structure of a piezoelectric actuator drive circuit of the present invention, and FIG. 3 shows the structure of a common rail type fuel injection system of a diesel engine to which the present invention is applied. Before the description of the piezoelectric actuator drive circuit, the fuel injection system will be described at first. An injector 1 is disposed correspondingly to each cylinder (actually, a plurality of injectors are disposed correspondingly to the number of cylinders, but only one injector 1 is shown in FIG. 1 and FIG. 2), and the engine receives fuel from common rail 54 communicated through a supply line 55. Fuel is injected with approximately the same pressure as that of the fuel pressure in the common rail

54 (referred to as common rail pressure hereinafter) into the combustion chamber of each cylinder from the injector 1. The common rail 54 receives fuel from a fuel tank 51 by means of a high pressure supply pump 53 with pressure, and stores it at high pressure.

Furthermore, the fuel supplied from the common rail 54 to the injector 1 is served not only for injection to the combustion chamber but also as the control oil pressure of the injector 1, and the fuel returns partially to the fuel tank 51 from the injector 1 through a low pressure drain line 56.

A CPU 61 calculates the fuel injection period and fuel injection volume based on the detected signal of the crank angle, supplies an injection signal corresponding to the calculated signal to a piezoelectric actuator drive circuit 2 to drive the piezoelectric actuator mounted on each injector 1, and the injector injects the fuel from the injector 1 for a predetermined period.

Furthermore, the CPU 61 controls the operation so that the injection pressure is properly corresponding to the operation condition informed from other sensors. To accomplish this operation, a pressure sensor 62 is provided on the common rail 54, the CPU 61 controls a metering valve 52 based on the common rail pressure so as to adjust the pressurized fuel supply volume supplied to the common rail 54.

FIG. 4 shows the structure of the injector 1, and the rod-like injector 1 is fixed so that the lower side portion of the injector 1 in the drawing is projected into the combustion

chamber through the combustion chamber wall shown in the schematic diagram of the engine. The injector 1 comprises a nozzle portion 1a, a back-pressure control portion 1b, and a piezoelectric actuator 1c in the order from the bottom.

A rear end portion of the needle 121 is held slidably in the sleeve-like body 104 of the nozzle portion 1a, and the needle 121 is seated on or unseated from a ring sheet 1041 formed on the nozzle body 104. High pressure fuel is introduced into the peripheral space 105 from the common rail 54 through the high pressure passage 101, and the fuel is injected from a nozzle hole 103 when the needle 121 is lifted. The fuel pressure supplied from the high pressure passage 101 exerts a force in the lift direction (upward direction) on the ring step surface 1211 of the needle 121 from the high pressure passage 101.

Fuel that is served as control oil is introduced into the rear of the needle 121 from the high pressure passage 101 through an in-orifice 107, and a back-pressure chamber 106 for generating the back-pressure of the needle 121 is formed. The back-pressure is exerted in the seating direction (downward) on the rear end surface 1212 of the needle 121 together with a spring 122 disposed in the back-pressure chamber 106.

The back-pressure is controlled by the back-pressure control portion 1b, and the back-pressure control portion 1b is driven by the piezoelectric actuator 1c having the piezo-stack 127.

The back-pressure chamber 106 is communicated normally to a valve chamber 110 of the back-pressure control portion 1b

through an out orifice 109. The valve chamber 110 is formed conical having the upper surface 1101 upward, the uppermost of the upper surface 1101 has a low pressure port 110a that communicates to the low pressure chamber 111, and the low pressure chamber 111 communicates to a low pressure passage 102 that communicates to the drain line 56. The bottom surface of the valve chamber 110 has a high pressure port 110b that is connected to the high pressure passage 101 through the high pressure control passage 108.

A ball 123 that has been formed by horizontally cutting the lower side of a spherical ball is disposed in the valve chamber 110. The ball 123 is served as a valve body that is movable vertically. The cut surface seats on the valve chamber bottom surface that is served as a valve seat (referred to as high pressure side sheet hereinafter) 1102 so as to close the high pressure port 110b when the ball 123 goes down and shuts down the high pressure control passage 108. On the other hand, when the ball 123 is lifted, the ball 123 seats on the upper surface that is served as a valve seat (referred to as low pressure side sheet) 1101 so as to close the low pressure port 110a and shuts down the valve chamber 110 from the low pressure chamber 111. Thereby, the back-pressure chamber 106 is communicated to the low pressure chamber 111 through the out orifice 109 and the valve chamber 110 when the ball 123 is lowered, and the back-pressure of the needle 121 is reduced and the needle 121 is unseated. On the other hand, when the ball 123 is lifted, the back-pressure chamber 106 is shut down from the low pressure chamber 111 and is communicated to only

the high pressure passage 101, the back-pressure of the needle 121 increases and the needle is seated.

The ball 123 is press-driven by means of the piezoelectric actuator 1c. Two pistons 124 and 125 having the different diameters of the piezoelectric actuator 1c are held slidably in the vertical hole 112 formed vertically above the low pressure chamber 111, and the piezo-stack 127 that expands or contracts in the vertical direction is disposed above the upper larger-diameter piston 125.

The larger-diameter piston 125 is maintained in contact with the piezo-stack by means of the spring 126 provided under the larger-diameter piston 125, and is displaced vertically by the same distance as the expansion/contraction value of the piezo-stack 127.

Fuel is filled in a space defined by the smaller-diameter piston 124 that is facing to the ball 123, the larger-diameter piston 125, and the vertical hole 112 to form a displacement enlarge chamber 113. When the piezo-stack 127 expands to displace the larger-diameter piston 125 downward and the fuel in the displacement enlarge chamber 113 is pressurized, the pressing pressure is transmitted to the smaller-diameter piston 124 through the fuel of the displacement enlarge chamber 113. Because the diameter of the smaller-diameter piston 124 is smaller than that of the larger-diameter piston 125, the expansion volume is enlarged and converted to the displacement of the smaller-diameter piston 124.

At first, the piezo-stack 127 is charged to be expanded

so that the small diameter piston 124 is lowered to press down the ball 123 when fuel is to be injected. Thereby, the ball 123 is lifted from the low pressure side seat 1101 and seated on the high pressure side sheet 1102 to communicate the back-pressure chamber 106 to the low pressure passage 102. As the result, the fuel pressure in the back-pressure chamber 106 is lowered. Thereby, the force exerted on the needle in the unseating direction becomes predominant over the force exerted in the seating direction, and the needle is unseated and the fuel injection starts.

On the other hand, when the injection is to be stopped, the piezo-stack 127 is discharged to result in contraction of the piezo-stack 127, and the press down force exerted on the ball 123 is released. At that time, the pressure in the valve chamber 110 is low and the high fuel pressure is exerted on the bottom surface of the ball 123 yet from the high pressure control passage 108, and the upward fuel pressure is exerted on the ball 123 as a whole. The ball 123 is unseated from the high pressure side sheet 1102 when pressing down force exerted on the ball 123 is released, and the ball 123 is seated on the low pressure side sheet 1101 again to increase the fuel pressure of the valve chamber 110. As the result, the needle 121 is seated and the injection is stopped.

FIG. 1 and FIG. 2 show the structure of the piezoelectric actuator drive circuit 2 that is served for charging and discharging the piezo-stack 127. For the purpose of description, the piezo-stack 127 comprises a piezo-stack 127A, a piezo-stack 127B, a piezo-stack 127C, and a piezo-stack 127D

corresponding to four cylinders in the order from that of the first cylinder. The piezoelectric actuator drive circuit 2 is provided with a charge/discharge circuit portion 2a, which is the main portion, and abnormality detection circuit portions 29E and 29F. The charge/discharge circuit portion 2a comprises a DC-DC converter 211 for generating DC voltage of several tens to several hundreds V from the power supply (+B) of an on-vehicle battery and a buffer capacitor 212 connected to the output terminal in parallel to form a DC power source 21, and supplies a voltage served for charging the piezo-stacks 127A to 127D. A general voltage-boost chopper type converter may be used as the DC-DC converter 211, energy is stored in an inductor 2111 while the switching element 2112 is being ON and the buffer capacitor 212 is charged from the inductor 2111 that generates a counter electromotive force while the switching element 2112 is being OFF through the diode 2113. The buffer capacitor 212 has a sufficient static capacitance so as to maintain an approximately constant voltage value when the piezo-stacks 127A to 127D are charged.

A first current supply passage 22a for supplying a current to the piezo-stacks 127A to 127D from the buffer capacitor 212 of the DC power source 21 through the inductor 23 is provided, and a first switching element 24a is provided between the buffer capacitor 212 and the inductor 23 in series. The first switching element 24a comprises a MOSFET, and is connected so that the parasitic diode (referred to as first parasitic diode hereinafter) 241a functions as the inverse bias with respect to the voltage between both ends of the buffer capacitor 212.

Furthermore, the inductor 23 and the piezo-stacks 127A to 127D form a second current supply passage 22b. The current supply passage 22b has a switching element 24b that is connected to the middle point between the inductor 23 and the first switching element 24a, and forms a closed circuit that include the inductor 23, the piezo-stacks 127A to 127D, and the second switching element 24b. The second switching element 24b also comprises a MOSFET, and is connected so that the parasitic diode (referred to as second parasitic diode) 241b functions as the inverse bias with respect to the voltage between both ends of the buffer capacitor 212.

The current supply passage 22a and 22b are used commonly for the respective piezo-stacks 127A to 127D, and the piezo-stacks 127A to 127D are selected as the drive target as described herein under. Switching elements (referred suitably to as selection switching element hereinafter) 25A, 25B, 25C, 25D, 25E, and 25F are connected to the respective piezo-stacks 127A to 127D in series. The first type selection switching elements 25A to 25D are connected to the piezo-stacks 127A to 127D through earth side connection terminals 201A, 201B, 201C, and 201D provided correspondingly to each cylinder, and current supply cables 203A, 203B, 203C, and 203D connects between the connection terminals 201A to 201D and the piezo-stacks 127A to 127D respectively. A selection switching element connected to the piezo-stacks 127A to 127D corresponding to an injection cylinder is turned on selectively out of the selection switching elements 25A to 25D when fuel is to be injected.

The second type selection switching elements 25E and 25F are connected to the piezo-stacks 127A to 127D through the power source side (non-ground side) connection terminals 201E and 201F. In other words, the portions between the power source side connection terminals (referred to as common terminal hereinafter) 201E and 201F and the piezo-stacks 127A to 127D are served as fork current supply cables 203E and 203F. On the other hand, The current supply cable 203E is commonly used for both piezo-stack 127A and piezo-stack 127B, and the other current supply cable 203F is commonly used for both piezo-stacks 127C and piezo-stack 127D. The selection switching element 25E is served to switch the current supply between ON and OFF to the bank of the injector 1 of the #1 and #2 cylinders on which the piezo-stacks 127A and 127B are mounted, and the selection switching element 25F is served to switch the current supply between ON and OFF to the bank of the injector 1 of the #3 and #4 cylinders on which the piezo-stacks 127E and 127F are mounted. For example, even if any one of the current supply cables 203E and 203F is ground-shorted, the selection switching elements 25E and 25F corresponding to the ground-shorted current supply cable is turned off and the function of the other bank is secured (limp form).

The MOSFET is used as each of the selection switching elements 25A to 25F, and the parasitic diodes (referred to as selection parasitic diode hereinafter) 251A, 251B, 251C, 251D, 251E, and 251F are connected so as to function as the inverse bias with respect to the buffer capacitor 212.

The controller 28 supplies control signals to each gate

of the switching elements 24a, 24b, 25A to 25F, a drive target piezo-stacks 127A to 127D are selected by turning on any one of the selection switching elements 25A to 25D as described hereinbefore, and pulse control signals are supplied to each gate of the switching element 24a and 24b to operate the switching elements 24a and 24b between ON and OFF. As the result, the charge control and discharge control of the piezo-stacks 127A to 127D are performed.

A relatively low resistant resistor 27E is provided commonly to the piezo-stacks 127A and 127B in series, and the same resistor 27F as the resistor 27E is provided commonly to the piezo-stack 127C and the piezo-stack 127B in series. The voltage between both ends is supplied to the controller 28 so that the charging current of the piezo-stacks 127A to 127D is detected.

A relatively low resistant resistor 27G is provided to the second switching element 24b in series. The voltage between both ends is supplied to the controller 28 so that the discharging current of the piezo-stacks 127A to 127D is detected.

Furthermore, the voltage between both ends (referred to as piezo-stack voltage hereinafter) of each of the piezo-stacks 127A to 127D, that is charging value, is supplied to the controller 28.

The controller 28 receives the injection signal from the CPU 61 as described hereinbefore to inject fuel into a selected injection cylinder. An injection signal is a binary signal, namely "L" or "H", the piezo-stacks 127A to 127D start to be charged at the rise of the signal, and start to be discharged at the fall

of the signal. The injection signal is generated one-to-one correspondingly to each cylinder, and the controller 28 maintains the corresponding selection switching elements 25A to 25D ON while the injection signal is being generated.

The controller 28 sets the ON period and OFF period of the first switching element 24a during charging control as described herein under, and generates the control signal to control the first switching element 24a. In other words, the first switching element 24a is turned on to supply an increasing charge current to the first current supply passage 22a. When the charge current reaches to a predetermined upper limit current value, the switching element 24a is turned off and enters in OFF period. At that time, because the counter electromotive force generated in the inductor 23 acts as a follow bias with respect to the parasitic diode 241b of the second switching element 24b, a decreasing flywheel current flows through the second current supply passage 22b based on the energy stored in the inductor 23, and the piezo-stacks 127A to 127D are charged increasingly. When the charge current reaches to the lower limit current value (approximately zero), the first switching element 24a is turned on and enters in ON period again, and such operation is repeated (multiple switching system). When the piezo-stack voltage reaches to the predetermined voltage, the switching element 24a is fixed at OFF and the charging is completed. The piezo-stacks 127A to 127D are charged as described hereinabove, the piezo-stacks 127A to 127D are resultantly expanded so as to press and lift the ball 123 with interposition of the displacement enlarge

chamber 113.

ON period and OFF period of the second switching element 24b are set as described herein under during discharge control, and the control signal for controlling the second switching element 24b.

In detail, the second switching element 24b is turned on to supply increasing discharge current to the second current supply passage 22b. When the discharge current reaches to the predetermined current value (referred to as upper limit current value hereinafter), the switching element 24b is turned off and enters in OFF period. At that time, a large counter electromotive force is generated in the inductor 23, a flywheel current generated from the energy stored in the inductor 23 flows through the first current supply passage 22a, and the energy is recovered in the buffer capacitor 212. When the discharge current reaches to the lower limit current value (approximately zero), the second switching element 24b is turned on again, and the above-mentioned operation is repeated. When the piezo-stack voltage reaches to 0, the switching element 24b is fixed at OFF, and the discharge is completed. As described hereinabove, the piezo-stacks 127A to 127D are discharged so as to be contracted, and the pressing force arising from the fuel pressure in the displacement enlarge chamber 113 exerted on the ball 123 is released and the ball 123 is seated.

If the piezo-stacks 127A to 127D are disabled to be charged due to disconnection of the current supply cables 203A to 203F, the injector 1 injects fuel continuously further after

the end of fuel injection period specified by the injection signal. However, in the case of the injector 1 shown in FIG. 4, the injector 1 is provided with a mechanical fail-safe mechanism that closes the valve when the time of charged state of the piezo-stack 127 exceeds a predetermined period. In detail, the injector 1 contracts and pressurizes the fuel in the displacement enlarge chamber 113 by mean of expansion of the piezo-stack 127 to generate the pressing pressure exerted on the ball 123, and the fuel pressure is sufficiently larger to overcome the upward pressing force exerted on the ball 123 when the ball is lifted. Therefore, the pressurized fuel in the displacement enlarge chamber 113 leaks to the low pressure space such as the low pressure chamber 111 little by little from sliding portion of the pistons 124 and 125, the lift magnitude of the ball 123 is decreased to reduce the fuel flow rate flowing from the back-pressure chamber 106 to the low pressure chamber 111, the back-pressure decreases gradually thereby, and at last the needle is seated to stop the fuel injection.

Furthermore, a first wiring pattern 202E that is conductive to the common terminal 201E and a second wiring pattern 202F that is conductive to the common terminal 201F are formed on the piezoelectric actuator drive circuit 2, and both wiring patterns are connected to the abnormality detection circuit portions respectively one-to-one correspondingly. Furthermore, the first cylinder injection signal (T1) and the second cylinder injection signal (T2) are supplied to the abnormality detection circuit portion 29E, and the third cylinder injection signal (T3)

and the fourth cylinder injection signal (T4) are supplied to the abnormality detection circuit portion 29F.

The first abnormality detection circuit portion 29E detects the abnormal conduction such as disconnection of the current supply cables 203A, 203B, and 203E for the first and second piezo-stacks 127A and 127B and detects the abnormal conduction such as the contact failure to the connection terminals 201A, 201B, and 201E. The second abnormality detection circuit portion 29F detects the abnormal conduction such as disconnection of the current supply cables 203C, 203D, and 203F for the third and fourth piezo-stacks 127C and 127D and detects the abnormal conduction such as contact failure to connection terminals 201C, 201D, and 201F. The abnormality detection signal generated from each of the abnormality detection circuit portions 29E and 29F is supplied to the CPU 61, and the CPU 61 performs the predetermined operation if the abnormality is found as described in the limp form.

The circuit configuration is common for both abnormality detection circuit portions 29E and 29F, and only the first abnormality detection circuit portion 29E will be described herein under. In FIG. 2 showing the detail of the abnormality detection circuit portion 29E, the voltage of the common terminal 201E is taken in through the wiring pattern 202E, and divided by means of a pair of resistors 311 and 312. The resistors 311 and 312 constitute a voltage detection means 31, and the voltage detection means 31 is easily handled by a logic calculation circuit located rear that is actuated at a voltage lower than the piezo-stack voltage. The divided common terminal voltage is

supplied to the (+) input terminal of a comparator 321. The comparator 321 compares the voltage of (+) input terminal with the voltage that has been generated from a constant voltage generator 322 and supplied to (-) input terminal, and determines whether the common terminal voltage is larger than the reference voltage specified by the constant voltage generator 322 or not, and generates a binary signal "H" or "L" depending on the comparison result. The binary signal is a signal that rises when the common terminal voltage exceeds the reference voltage (this signal is referred to as first comparison signal). For the above, the magnitude of the above-mentioned reference voltage is set in consideration of the target charge voltage of the piezo-stacks 127A and 127B so as to check whether the piezo-stacks 127A and 127B are in the charge holding state or not.

Furthermore, the binary signal generated from the comparator 321 is inverted by means of a NOT gate circuit 323, and is served as the second comparison signal that rises when the common terminal voltage becomes lower than the reference voltage contrarily to the first comparison signal. The comparator 321, the constant voltage generator 322, and the NOT gate circuit 323 constitute a comparison means 32, and the comparison means 32 generates two comparison signals having the inverse phase each other.

The first comparison signal is supplied to a set terminal of an S-R flip-flop circuit 35 through the first AND gate circuit 33 that is served as the set input value fixing means. Furthermore, the second comparison signal is supplied to a reset

terminal of an S-R flip-flop circuit 35 through the second AND gate circuit 34 that is served as the reset input value fixing means.

A binary counter 36 that receives the output (Q) of the S-R flip-flop circuit 35 as the input and is served as a counting means comprising two D-flip-flop circuits 361 and 362 is provided. The inverse output of the upper bit of the binary counter 36 is supplied to the third AND gate circuit 37. Not only the above-mentioned inverse output but also the output (Q) of the S-R flip-flop circuit 35 is supplied to the AND gate circuit 37, and the output of the AND gate circuit 37 is supplied to the CPU 61 as the abnormality detection signal for checking whether the conduction of the current supply cables 203A to 203F is abnormal or not.

The inverted phase output of the binary counter 36 is supplied to the first AND gate circuit 33 together with the comparison signal of the first comparative signal. Therefore, the output value (non-inverted output) of the binary counter 36 remains in "L" until the binary counter 36 counts "10", and the first comparison signal is actually supplied to the set terminal of the S-R flip-flop circuit 35. When two pulses are supplied to the binary counter 36, the inverted phase output (inverted output) of the binary counter 36 is changed from "H" to "L", and the set terminal of the S-R flip-flop circuit 35 is fixed at "L" and becomes insensitive to the first comparison signal.

An OR gate circuit 38 to which the first injection signal (T1) corresponding to the first piezo-stack 127A and the

second injection signal (T2) corresponding to the second piezo-stack 127B are supplied is provided, and the output is supplied to the second AND gate circuit 34 together with the second comparison signal. Therefore, while any one of the injection signal (T1) and the injection signal (T2) is being supplied, the second comparison signal is supplied to the reset terminal of the S-R flip-flop circuit 35.

Furthermore, a rising edge detection circuit 39 to which the logical output of the OR gate circuit 38 is supplied as the input is provided, the rising edge of an output signal waveform of the OR gate circuit 38 is detected. When a rising edge is detected, reset signals are supplied to the respective D-flip-flop circuit 361 and 362 of the binary counter 36.

The abnormality detection circuit portion 29F receives the common terminal voltage of the common terminal 201F, the #3 cylinder injection signal (T3), and the #4 cylinder injection signal (T4), and supplies an abnormality detection signal to check whether the current supply cables 203C, 203D, and 203F are abnormal or not.

FIG. 5, FIG. 6, and FIG. 7 are timing charts showing each portion of the respective abnormality detection circuits, and the operation that is to be formed when the conduction failure is found on the current supply cables 203A and 203F during charge holding period of the piezo-stacks 127A to 127D will be described with reference to these figures. The #1 and #2 cylinder abnormality detection circuit portion 29E will be described. FIG. 5 shows a normal state in which there is no conduction abnormality

in any of the #1 and #2 cylinders, and in this initial state the detection voltage is lower than the reference voltage, and the first comparison signal is "L" and the second comparison signal is "H". The output value of the second AND gate circuit 34 is "L". When an injection signal (T1) for selecting the #1 cylinder rises, the output value of the second AND gate circuit 34 changes to "H". As the result, the output value of the S-R flip-flop circuit 35 remains in "L" regardless of the previous output value. Therefore, the output value, namely abnormality detection, of the third AND gate circuit 37 is "L".

Furthermore, because the binary counter 36 is reset and the injection signal (T1) rises, the one input value of any one of the AND gate circuits 33 and 34 is "H", the input value of the set terminal of the S-R flip-flop circuit 35 is equal to that of the first comparison signal, and the input value of the reset terminal is equal to that of the second comparison signal.

When any one of the piezo-stacks 127A and 127B starts to be charged and the piezo-stack voltage exceeds the reference voltage, the first comparison signal rises from "L" to "H", and the input value supplied to the set terminal of the S-R flip-flop circuit 35 resultantly changes from "L" to "H" and the output value changes from "L" to "H". Because the upper bit inverted output of the binary counter 36 is "H", the abnormality detection signal changes to "H".

When the injection signal (T1) changes from "H" to "L", the output value of the OR gate circuit 38 changes to "L", and the input value of the reset terminal of the S-R flip-flop circuit

35 is fixed at "L". Thereby, the piezo-stack 127A or 127B starts to be discharged, the output value of the S-R flip-flop circuit 35 remains in "H" even though the common terminal voltage falls below the reference voltage, and the abnormality detection signal remains in "H".

Through the above-mentioned operation, the CPU 61 determines the #1 cylinder current supply cables 203A and 203E to be normal based on the abnormality detection signal at the predetermined timing after, for example, the injection signal (T1). As described hereinabove, because the third AND gate circuit 37 holds the state of falling down of the previous injection signal (T1) until the next injection signal (T2) is supplied, the timing for monitoring the abnormal detection signal by means of the CPU 61 is not limited substantially.

Thereafter, the injection period of the #2 cylinder comes, the injection signal (T2) is supplied for a predetermined period, and the same signal change occurs in each portion as in the case of the #1 cylinder.

Next, the operation that occurs when the current supply cables 203B and 203E are disconnected completely or come off from the common terminal 201E during injection period of the #2 cylinder will be described with reference to FIG. 6.

The same operation proceeds until the disconnection occurs, but the common terminal voltage drops toward 0V when the disconnection occurs. On the way to 0V, the common terminal voltage becomes lower than the reference voltage, the first comparison signal and the input value of the set terminal of the

S-R flip-flop circuit 35 change from "H" to "L", and the second comparison signal and the input value of the reset terminal of the S-R flip-flop circuit change from "L" to "H". Thereby, the output value of the S-R flip-flop circuit 35, namely the input value of the third AND gate circuit 37, changes from "H" to "L". Thereby, the abnormality detection signal also changes from "H" to "L". This state remains unchanged after falling down of the injection signal (T2). As the result, the CPU 61 can detect the abnormal conduction of the current supply cables 203B and 203E.

Next, the operation that occurs when jittering occurs on the current supply cables 203B and 203E during the injection period of the #2 cylinder will be described with reference to FIG. 7.

The same operation proceeds as described hereinabove until the first conduction shutdown occurs, but the common terminal voltage drops to 0V and the conduction is restored again, and the common terminal voltage restores to a voltage that is approximately equal to the target voltage. This operation is repeated. The first and second comparison signals change between "H" and "L" repeatedly.

On the other hand, when the conduction is restored after the first conduction shutdown, the common terminal voltage exceeds the reference voltage, and the input value of the set terminal of the S-R flip-flop circuit 35 changes from "L" to "H". This change is the second change subsequent to the charge.

Thereby, because the output value of the lower bit D flip-flop circuit 361 changes again to "L" and the output value

of the upper D flip-flop circuit 362 changes to "H", the output value of the first AND gate circuit 33 to which the inverse output of the upper bit D flip-flop circuit 362 is supplied changes to "L". The abnormality signal remains in "L".

Next, when the conduction shutdown occurs again, the second comparison signal changes from "L" to "H", the input value of the reset terminal of the S-R flip-flop circuit 35 changes to "H", and the output value of the S-R flip-flop circuit 35 changes to "L" resultantly.

Thereafter, the input value of the set terminal of the S-R flip-flop circuit 35 remains in "L" state due to the inverted output ("L") of the upper bit D flip-flop circuit 362 even though the conduction shutdown and conduction restoration are repeated and the first comparison signal changes from "L" to "H", and the abnormality detection signal remains in "L" state without count-up of the binary counter 36.

This abnormality detection remains in "L" state even after the injection signal (T2) falls down. Through the sequential operation described hereinabove, the CPU 61 can detect the abnormal conduction of the current supply cables 203B and 203E.

As described hereinabove, according to the present embodiment, the abnormal conduction such as complete disconnection and jittering can be found based on a single abnormality detection signal.

Furthermore, it is possible to distinguish between the complete disconnection and jittering based on the output value

(or inverted output value) of the upper bit D flip-flop circuit 362 when the abnormality detection is in "L" state that indicates the abnormality.

In the above-mentioned embodiment, the second AND gate circuit 34 is provided so that the input value of the reset terminal of the S-R flip-flop circuit 35 is fixed in "L" state when the injection signal (T1) and the injection signal (T2) fall down, the output "H" for indicating that the current supply cables 203A, 203B, and 203E are normal is supplied from the AND gate circuit 37 even though the second comparison signal is "H" due to the discharge of the piezo-stacks 127A and 27B. However, if the determination timing of the CPU 61 occurs before the common terminal voltage falls down below the reference voltage due to the discharge, for example, at the time point of falling down of the injection signal, it is not always necessary to provide the second AND gate circuit 34.

In the embodiment described hereinabove, the injector 1 stops fuel injection after elapse of a predetermined period by means of the mechanical fail-safe mechanism even if the abnormal conduction occurs after the piezo-stacks 127A to 127D are charged. However, it is possible to stop the fuel injection earlier by executing the next control when the abnormality is found if the abnormality involves coming off of the current supply cable 203E from the common terminal 201E or disconnection of the common portion of the current supply cable 203E. FIG. 8 shows the state of portions when fuel injection is controlled to stop, and a case in which the piezo-stack 127A of the #1 cylinder injector is

disconnected will be described herein under.

When the injection signal (T1) rises, the piezo-stack 127A of the #1 cylinder is charged up to the target voltage. When the piezo-stack voltage exceeds the valve opening voltage of the injector 1 near the target voltage, the injector 1 is opened and starts fuel injection. Subsequently, when the injection signal (T1) falls down at the time calculated by means of the CPU 61, the injector 1 maintains the valve in open state without discharge due to the abnormal conduction instead of discharge of the piezo-stack 127A if it is normal.

On the other hand, the CPU 61 monitors the abnormality detection signal ("L") that indicates the abnormality at the predetermined timing after falling down of the injection signal (T1) as described hereinabove, and the selection switching element 25B of the piezo-stack 127B of the #2 cylinder is turned on. Because both piezo-stacks 127A and 127B are conductive through the fork-branch portion of the current supply cable 203E, a current flows through the piezo-stack 127A of the #1 cylinder, the current supply cable 203E, the piezo-stack 127B of the #2 cylinder, the current supply cable 203B, the selection switching element 25B of the #2 cylinder, the selection parasitic diode 251A of the #1 cylinder, and the current supply cable 203A. Thereby, the charge moves from the piezo-stack 127A of the #1 cylinder to the piezo-stack 127B of the #2 cylinder, the piezo-stack voltage of the #1 cylinder falls down below the valve opening voltage, and the valve of the injector 1 of the #1 cylinder is closed. Though the voltage between both ends of the piezo-stack 127B of

the #2 cylinder rises, the voltage will not exceed the valve opening voltage because the charge is divided by both piezo-stacks 127A and 127B.

As described hereinbefore, the injector 1 of the piezo-stacks 127A to 127D that are disabled to discharge stops fuel injection quickly.

(Second Embodiment)

The structure of another piezoelectric actuator circuit of the present invention is shown. An abnormality detection circuit portion having another structure is used, and the same portions that function substantially as those employed in the first embodiment are given the same characters, and the difference from the first embodiment will be mainly described.

The abnormality detection circuit portion 29E′ for the #1 and #2 cylinders is provided with a counter 36′ that is served as a counting means receives the output of the comparator 321 that constitutes the comparison means 32′, and the number of supplied pulse is counted. The counter 36′ resets, for example, at the rising timing of the injection signal. The CPU 31′ monitors the count value of the counter 36′, for example, at the falling down timing of the injection signal, and determines whether the abnormal conduction occurs on the current supply cables 203A to 203F during charge holding state of the piezo-stack or not depending on the number of counts. In other words, if the count value is "0", it means that the common terminal voltage never falls down below the reference voltage during the output period of the injection signal, and the injection is determined to be normal

(refer to FIG. 5). If the count value is "1", it means that the common terminal voltage falls down below the reference voltage once during the output period of the injection signal (refer to FIG. 6). If the count value is "2 or higher", it means that the common terminal voltage falls down and rises up several times across the reference voltage, and the jittering is found (refer to FIG. 7).

The abnormality detection circuit portion for the #3 and #4 cylinders has the same structure though not shown in the drawing, and operates similarly.

As described hereinabove, the abnormal conduction of the current cables 203A to 203F can be detected.

Furthermore, the injector has the structure in which the driving force generated by means of the piezo-stack is transmitted to the ball by way of the fuel pressure of the displacement enlarge chamber, however, the present invention may be applied to a fuel injection system of an injector having the structure in which a single piston pushed by a piezo-stack pushes a ball directly without providing a displacement enlarge chamber.

Furthermore, the examples in which the present invention is applied to the fuel injection system are described in each embodiment, but the present invention may be applied to a piezoelectric actuator drive circuit for driving a piezoelectric actuator that is used for other applications.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[FIG. 1] A circuit diagram of a piezoelectric actuator drive circuit of the present invention for driving a piezoelectric

actuator mounted on an injector fabricated so as to be used as a fuel injection system.

[FIG. 2] A circuit diagram showing the piezoelectric actuator driving circuit partially.

[FIG. 3] A whole structure diagram of the fuel injection system.

[FIG. 4] A structural diagram mainly showing the injector of the fuel injection system.

[FIG. 5] A first timing chart showing operation of each portion of the piezoelectric actuator drive circuit.

[FIG. 6] A second timing chart showing operation of each portion of the piezoelectric actuator drive circuit.

[FIG. 7] A third timing chart showing operation of each portion of the piezoelectric actuator drive circuit.

[FIG. 8] A timing chart showing the operation of each portion of the fuel injection system.

[FIG. 9] A partial circuit diagram showing another piezoelectric actuator of the present invention for driving a piezoelectric actuator mounted on an injector of another fuel injection system structure of the present invention.

[DESCRIPTION OF REFERENCE NUMERALS]

1… injector

1a… nozzle portion

1b… back-pressure control portion

1c… piezoelectric actuator

127, 127A, 127B, 127C, and 127D… piezo-stack

2… piezoelectric actuator drive circuit

2a… charge/discharge circuit portion

29E, 29F, and 29E'… abnormality detection circuit portion

31… voltage detection means

311 and 312… resistor

32 and 32'… comparison means

321… comparator

322… constant voltage generator

323… NOT gate circuit

33… AND gate circuit (set input value fixing means)

34… AND gate circuit (reset input value fixing means)

35… S-R flip-flop circuit

36… binary counter (counting means)

36'… counter (counting means)

[NAME OF DOCUMENT] ABSTRACT

[Object]

The invention is used to detect the disconnection of a cable for connecting between a piezo-stack and a current supply connection terminal when the piezo-stack of a piezoelectric actuator is in charge holding state.

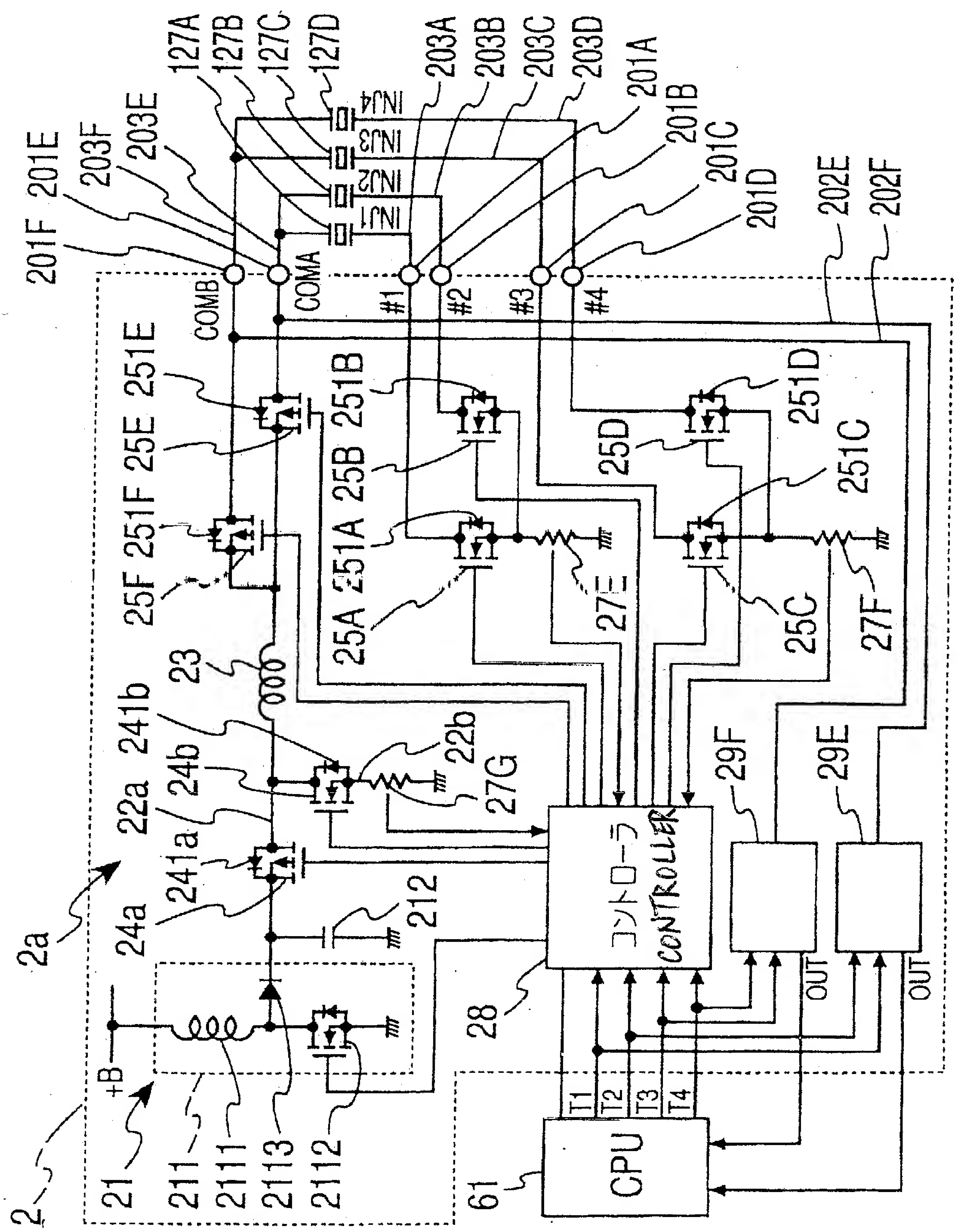
[Solution]

An abnormality detection circuit portion 29E of a piezoelectric actuator drive circuit is provided with a voltage detection means 31 for detecting the voltage of the connection terminal 201E on the non-ground side and a comparison means 32 for generating a comparison signal to check whether a detected voltage is higher than the reference voltage or not based on the comparison result between the detected voltage and the reference voltage that has been set previously, and if the detected voltage is lower than the reference voltage, the cables 203A, 203B, and 203E are determined to be disconnected.

【書類名】　図面

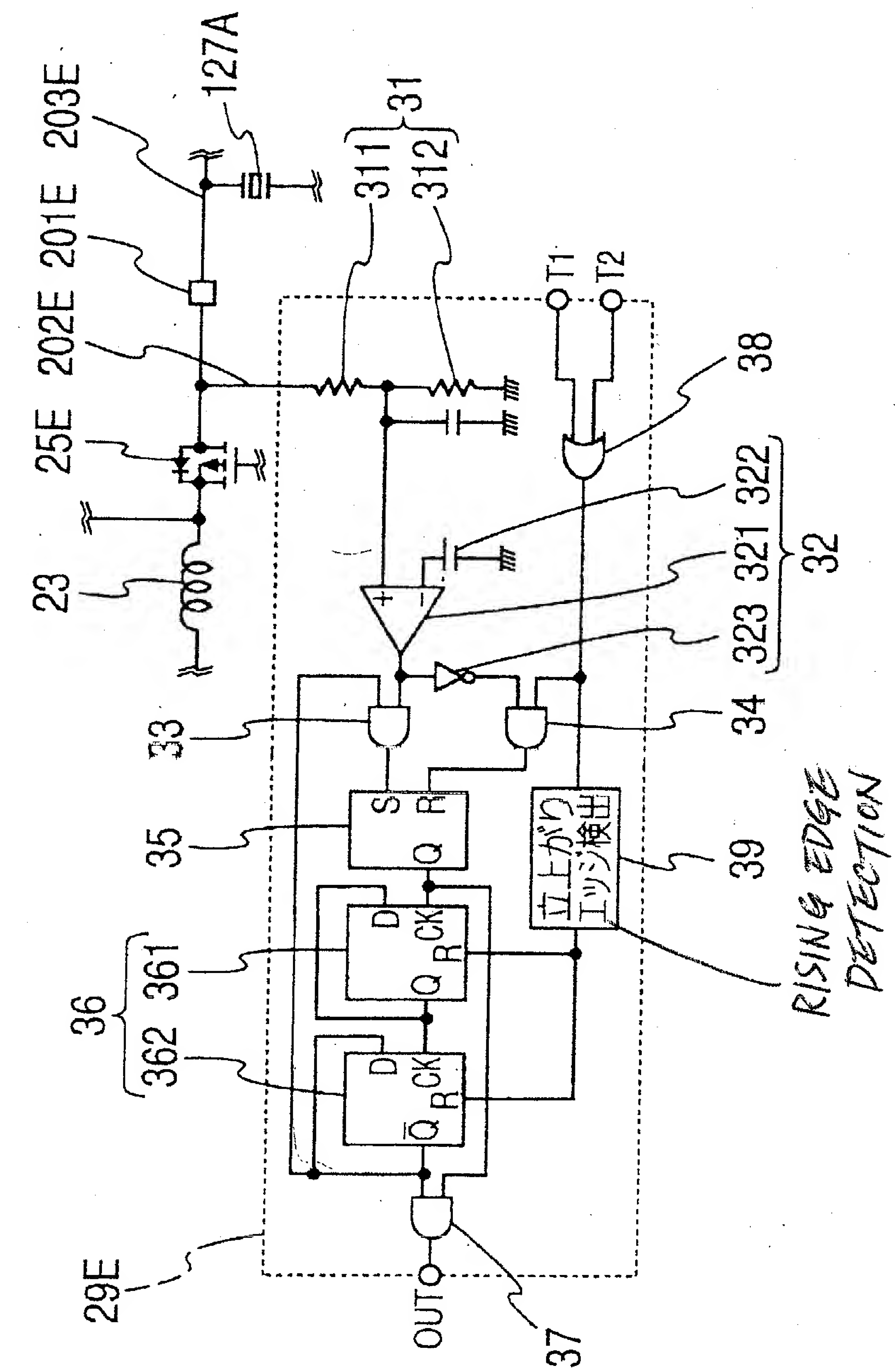
【図１】

FIG. 1



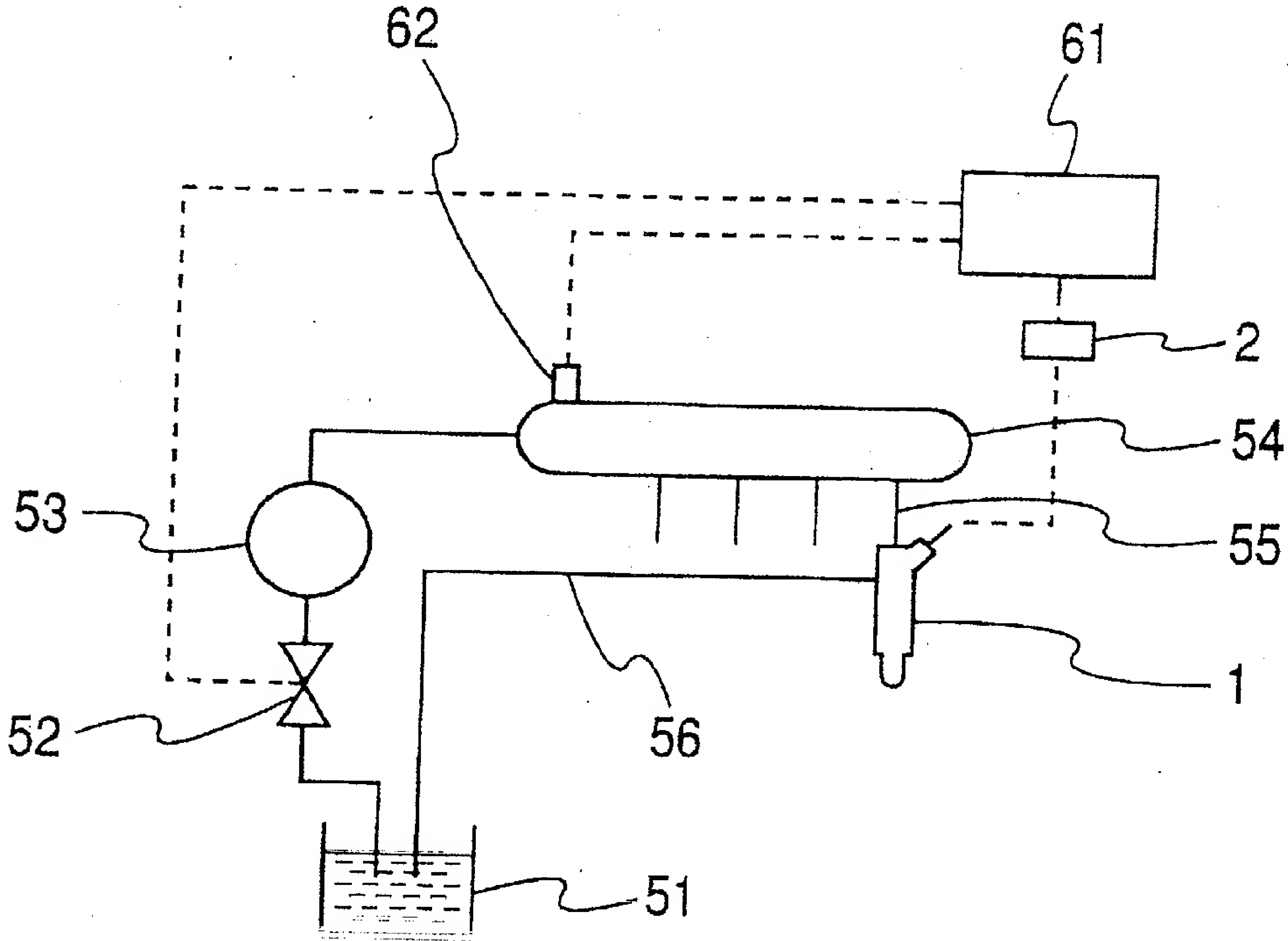
【図２】

FIG. 2


23
25E
202E
201E
203E
127A
311
312
31
T1
T2
38
322
321
323
32
33
34
35
39
立上がり
エッジ検出
RISING EDGE DETECTION
361
362
36
29E
OUT
37

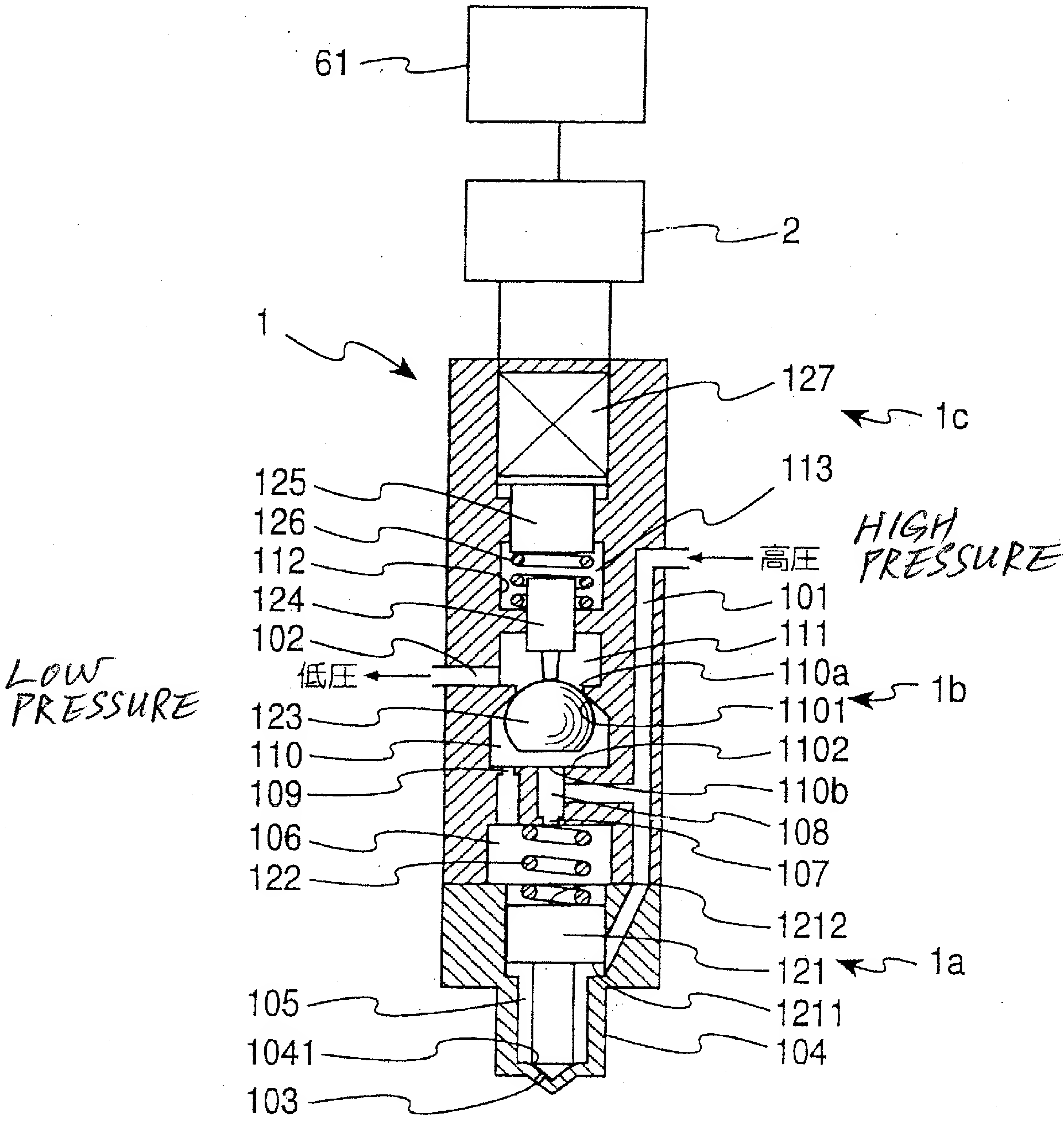
【図３】

FIG. 3



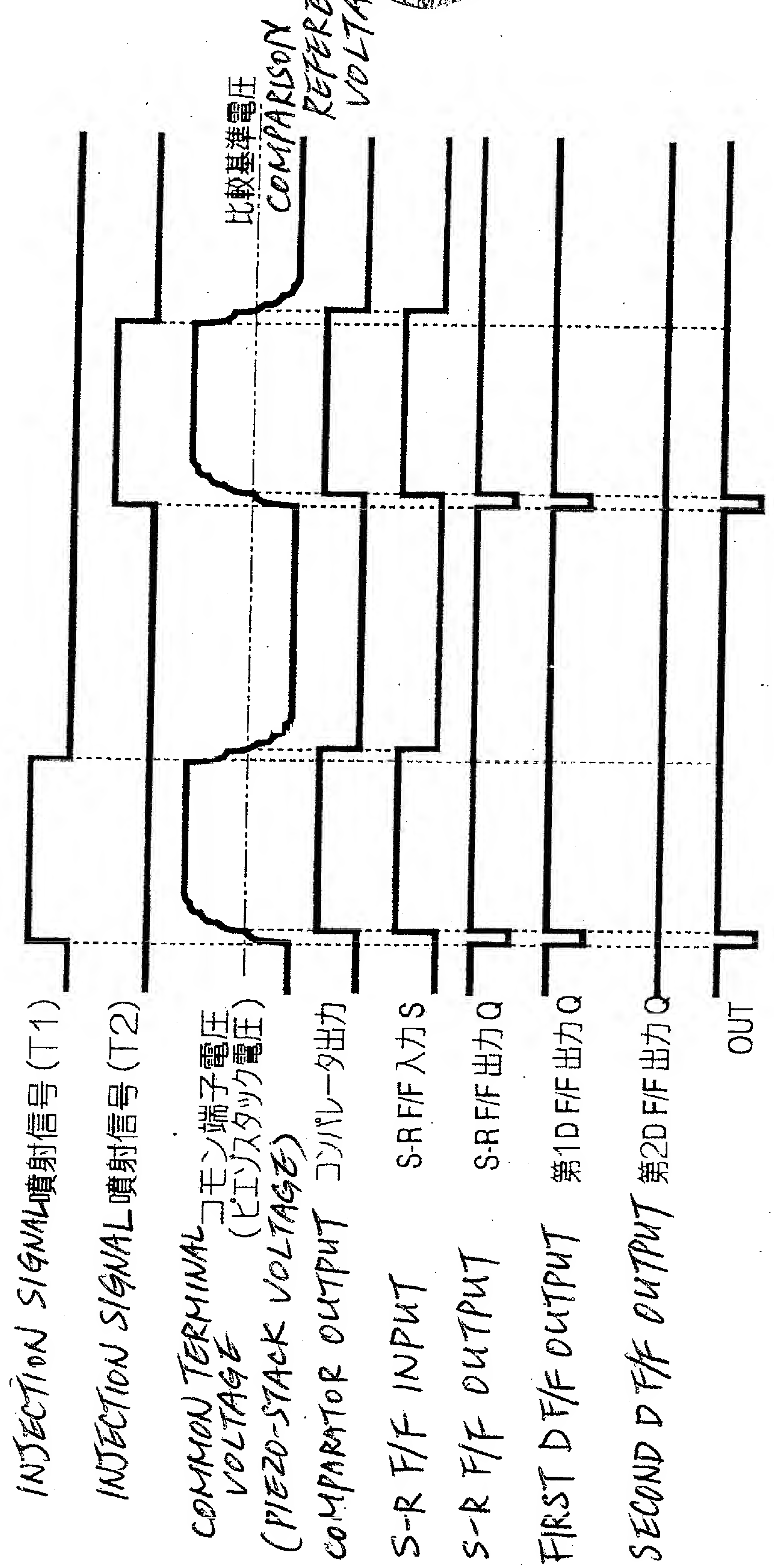
【図４】

FIG. 4


61
2
1
127
1c
113
125
126
112
124
102
高圧
HIGH PRESSURE
101
111
110a
1b
LOW PRESSURE
低圧
123
1101
110
1102
109
110b
106
108
122
107
1212
121
1a
105
1211
1041
104
103

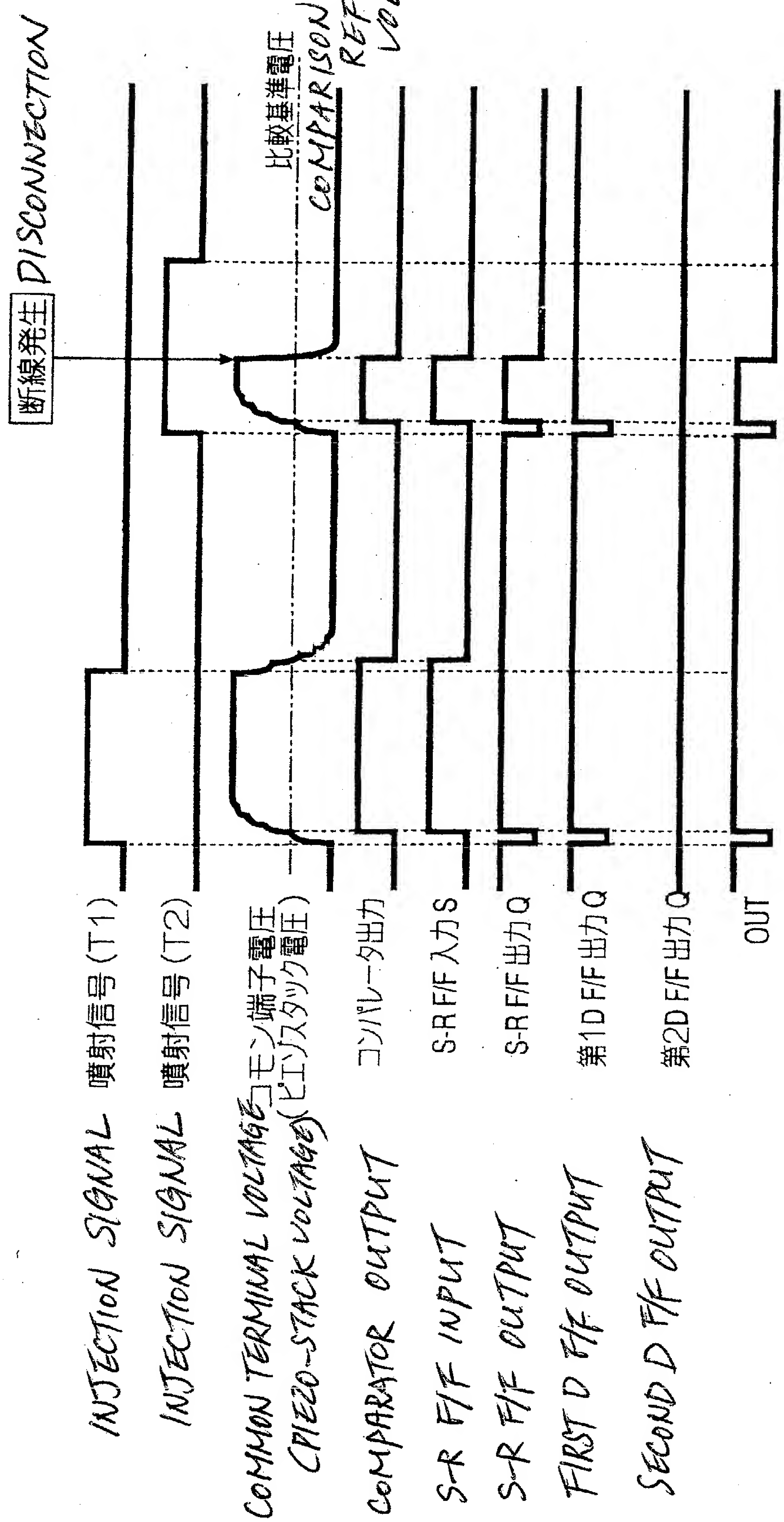
【図５】

FIG. 5


INJECTION SIGNAL 噴射信号 (T1)
INJECTION SIGNAL 噴射信号 (T2)
COMMON TERMINAL VOLTAGE コモン端子電圧
(PIEZO-STACK VOLTAGE) (ピエゾスタック電圧)
比較基準電圧
COMPARISON REFERENCE VOLTAGE
COMPARATOR OUTPUT コンパレータ出力
S-R F/F INPUT S-R F/F 入力 S
S-R F/F OUTPUT S-R F/F 出力 Q
FIRST D F/F OUTPUT 第1D F/F 出力 Q
SECOND D F/F OUTPUT 第2D F/F 出力 Q
OUT

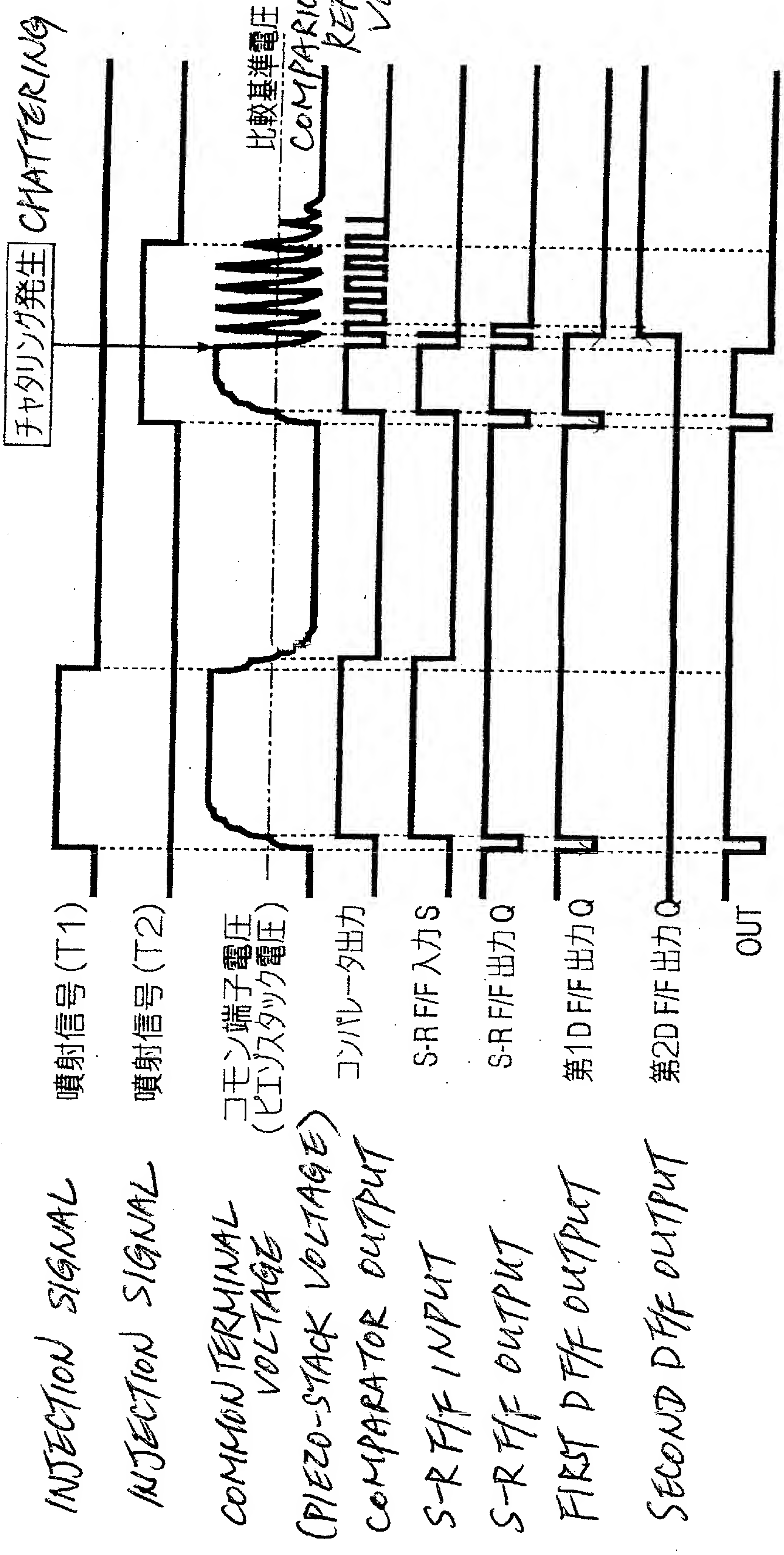
【図６】

FIG. 6


断線発生
DISCONNECTION
比較基準電圧
COMPARISON REFERENCE VOLTAGE
INJECTION SIGNAL 噴射信号(T1)
INJECTION SIGNAL 噴射信号(T2)
COMMON TERMINAL VOLTAGE コモン端子電圧
(PIEZO-STACK VOLTAGE) (ピエゾスタック電圧)
COMPARATOR OUTPUT コンパレータ出力
S-R F/F INPUT S-R F/F 入力S
S-R F/F OUTPUT S-R F/F 出力Q
FIRST D F/F OUTPUT 第1D F/F 出力Q
SECOND D F/F OUTPUT 第2D F/F 出力Q
OUT

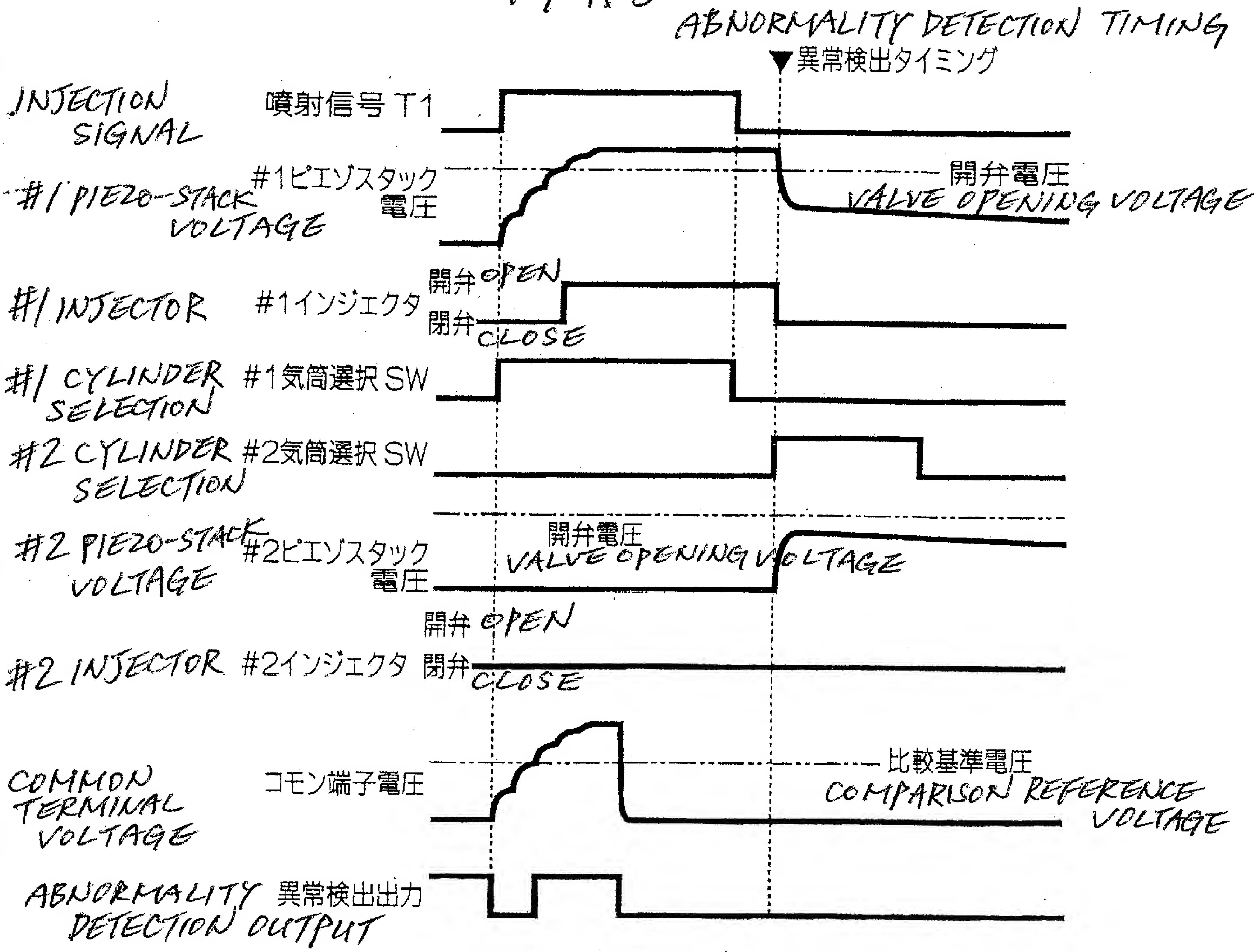
【図７】

FIG. 7


噴射信号(T1)
INJECTION SIGNAL
噴射信号(T2)
INJECTION SIGNAL
コモン端子電圧
(ピエゾスタック電圧)
COMMON TERMINAL VOLTAGE
(PIEZO-STACK VOLTAGE)
コンパレータ出力
COMPARATOR OUTPUT
S-R F/F 入力 S
S-R F/F INPUT
S-R F/F 出力 Q
S-R F/F OUTPUT
第1D F/F 出力 Q
FIRST D F/F OUTPUT
第2D F/F 出力 Q
SECOND D F/F OUTPUT
OUT
チャタリング発生
CHATTERING
比較基準電圧
COMPARION REFERENCE VOLTAGE

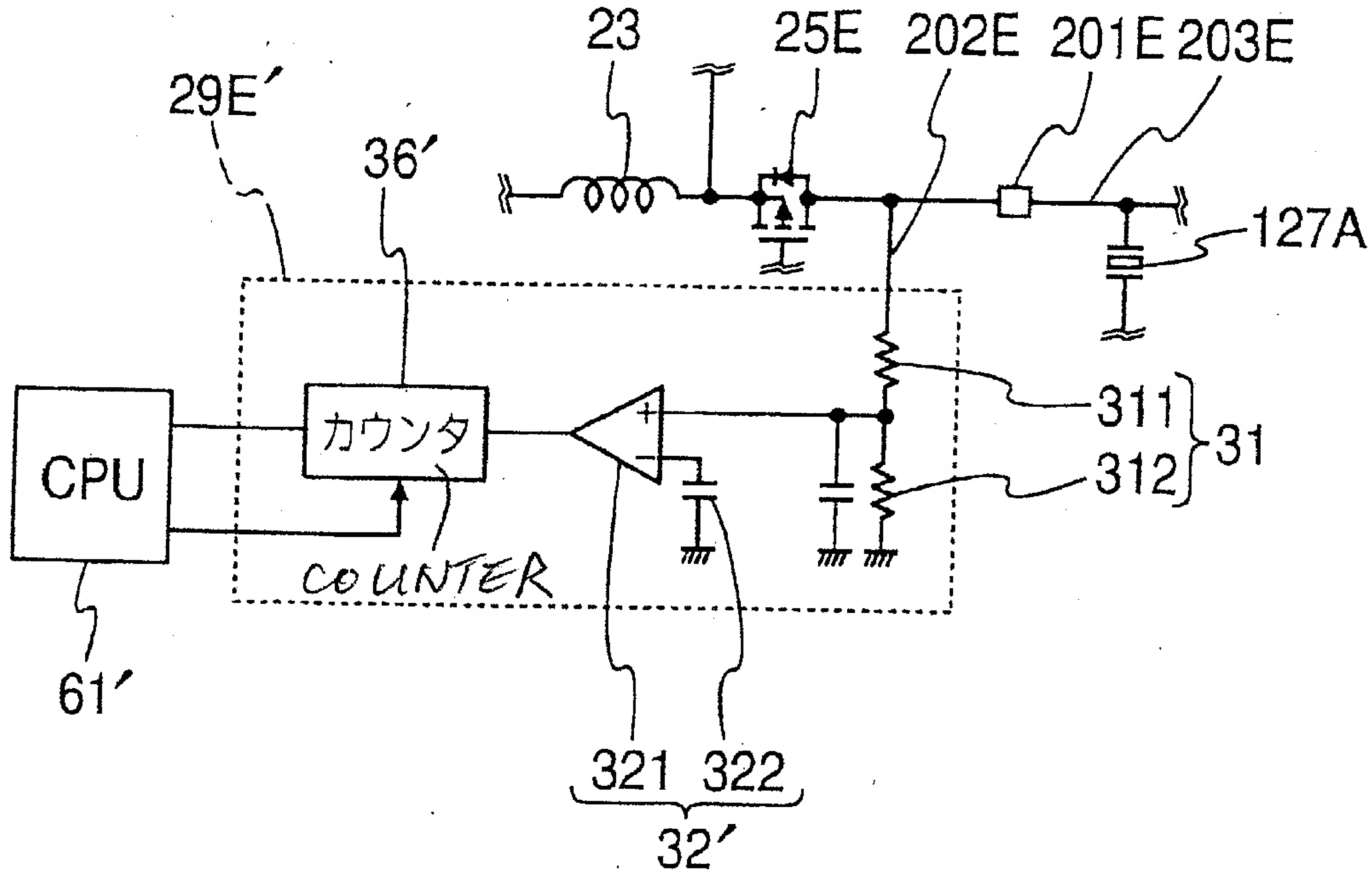
【図８】

FIG. 8


ABNORMALITY DETECTION TIMING
異常検出タイミング
INJECTION SIGNAL
噴射信号 T1
#1 PIEZO-STACK VOLTAGE
#1ピエゾスタック電圧
開弁電圧
VALVE OPENING VOLTAGE
#1 INJECTOR
#1インジェクタ
開弁 OPEN
閉弁 CLOSE
#1 CYLINDER SELECTION
#1気筒選択 SW
#2 CYLINDER SELECTION
#2気筒選択 SW
#2 PIEZO-STACK VOLTAGE
#2ピエゾスタック電圧
開弁電圧
VALVE OPENING VOLTAGE
#2 INJECTOR
#2インジェクタ
開弁 OPEN
閉弁 CLOSE
COMMON TERMINAL VOLTAGE
コモン端子電圧
比較基準電圧
COMPARISON REFERENCE VOLTAGE
ABNORMALITY DETECTION OUTPUT
異常検出出力

【図９】

FIG. 9


23
25E
202E
201E
203E
29E′
36′
127A
CPU
カウンタ
COUNTER
311
312
31
61′
321
322
32′